U.S. ARMY TANK AUTOMOTIVE RESEARCH, DEVELOPMENT AND ENGINEERING CENTER

Fire Suppression M&S Validation (Status & Challenges)

Systems Fire Protection Information Exchange
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Outline

- Introduction
- Physics being solved
- Reduced Chemical Kinetics:
  - Complete description of suppression is complex
  - HFP (+SBC); Halon (+SBC), potassium acetate solution.
- Fire Suppression Evaluation Criteria
- Simulation Results & Comparison with Test Data:
  - Cup Burner
  - Exploratory Test Box
  - Crew Compartment
    - » Concentration
    - » Live Fire Simulation
  - Engine Compartment (In-Progress)
- Summary & Future Work

Introduction

- **Develop a Computational Fluid Dynamics (CFD) capability for modeling suppression events in ground combat vehicles.**

- **Using known component parameters, M&S allows:**

  - **To conduct trade studies between various layouts.**

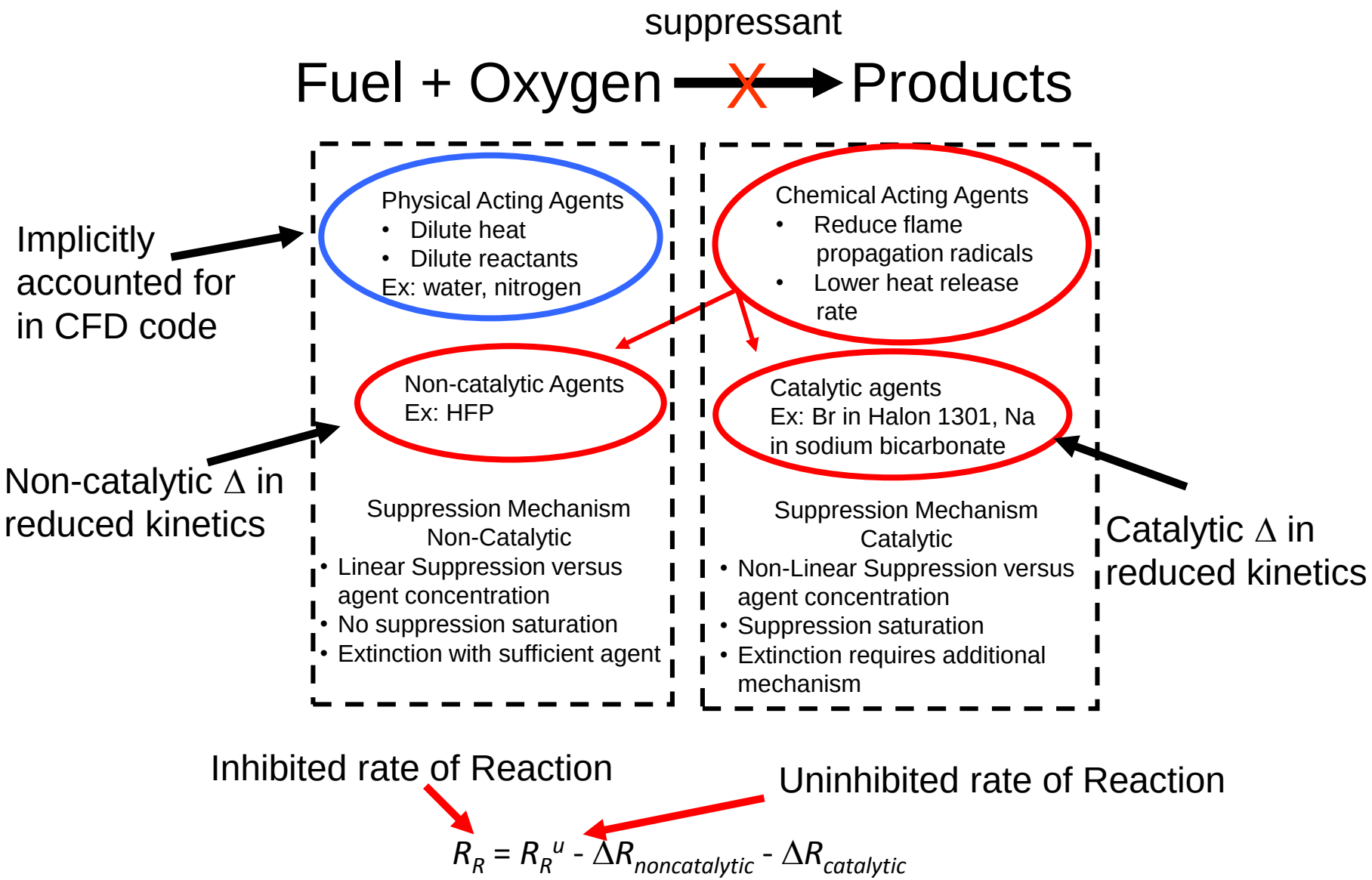
  - **Reduces time and cost to compare multiple configurations.**

  - **Provides insight by complementing testing**

Physics Being Solved

Transient Analysis	• Model fuel spray and fire ball development • Suppressant Discharge + Acid Mitigation
Turbulence Model	• K-Epsilon with Realizable Wall functions • Segregated Solver
Lagrangian Physics	• Two-Way Coupling • Evaporation & Devolatization
Suppressant Discharge	• Discharge from Pressurized bottle • Liquid & Vapor Phase
Combustion Model	• Hybrid EBU with finite rate Kinetics • 14 Species & 12 reactions
Radiation Model	• Participating Media Discrete Ordinate Method • WSG model for CO2, H2O and Soot
Suppression	• Catalytic & Non-Catalytic effects • Acid Levels

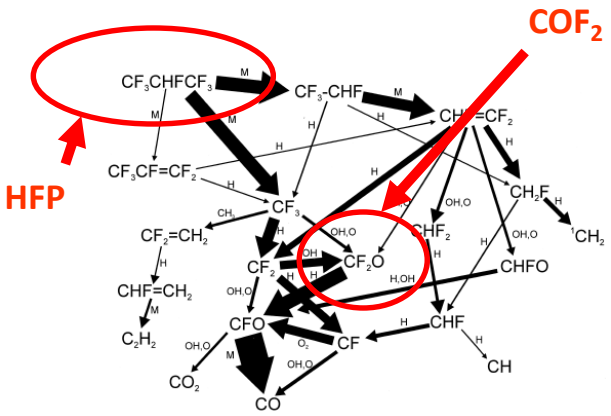
Inhibition of JP-8 Combustion



Overview of Reduced Kinetics Scheme for FM200

Inhibition of JP-8 combustion by HFP (FM200) and/or sodium bicarbonate powder (SBC)

Mechanism: ≈800 chemical reactions
(200 for hydrocarbon fuel—more for JP-8; 600 for fluorine chemistry)
Predicts flame inhibition, acid gas formation
Useful for modeling laboratory experiments
Not useful for modeling large-scale fire suppression



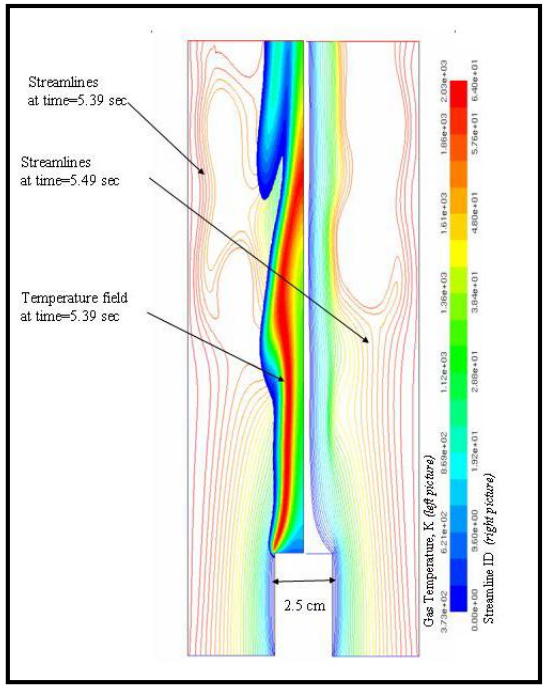
- **R1**: $JP\text{-}8 + O_2 \Rightarrow CO + CO2 + H_2O$
- **R2**: $CO + O_2 \Leftrightarrow CO_2$
- **R3**: $HFP + JP\text{-}8 + O_2 \Rightarrow HF + COF_2 + CO + H_2O$
- **R4**: $COF_2 + H_2O \Rightarrow CO_2 + HF$
- **R5**: $NaHCO_3(s) \Rightarrow CO_2 + NaOH(g)$
- **R6**: $NaOH(g) \Leftrightarrow NaOH(hvy\_gas)$ (hvy_gas = heavy-gas approximation)
- **R7**: $NaOH(hvy\_gas) + HF \Rightarrow NaF(hvy\_gas) + H_2O$
- **R8**: $NaHCO_3(s) + HF \Rightarrow NaF(hvy\_gas) + H_2O + CO_2$
- **R9**: $JP\text{-}8 + O_2 \Rightarrow C\ (soot) + H_2O$
- **R10**: $C\ (soot) + O_2 \Rightarrow +CO_2$

Kinetic Rate Coefficient for each equation is given in Arrhenius form (three-parameter)
Halon Kinetics includes HBr acid

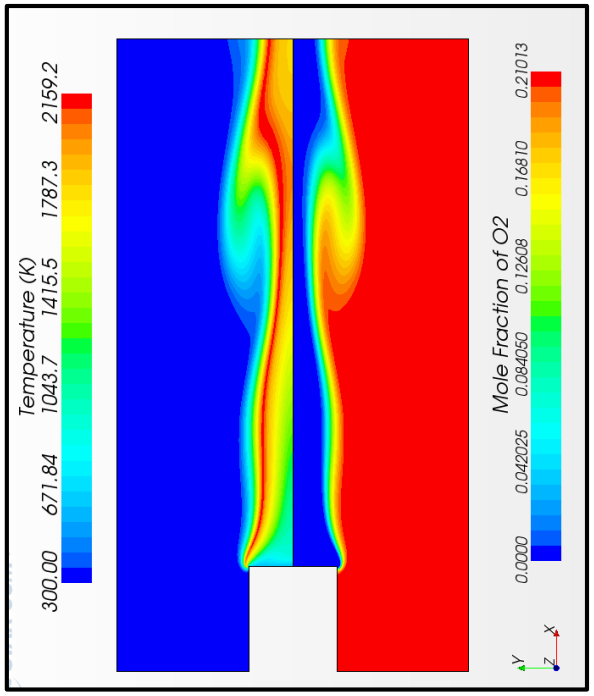
Selected Crew AFES performance criteria:

Parameter	Requirement	Simulation
Fire Suppression	Extinguish Flames without reflash	Y
Skin Burns	Less than Second degree burns	Y
Overpressure	Lung damage <11.6 psi; Ear damage ≤ 3.6 psi	Y
Acid Gases	Acid gas, 5 min dose ($HF + HBr + 2 \cdot COF_2$) < 746 ppm-min	Y
Agent Concentration	<Lowest Observed Adverse Effects Level	Y
Oxygen Levels	Not below 16%	Y
Discharge Impulse Noise	No hearing protection limit < 140 dB	N
Discharge Forces	Acceleration ≤ 8 g and pressure pulse ≤ 10 psig at crew locations	N
Fragmentation	Ejected non-agent particles ≤ 300 micrometers	N

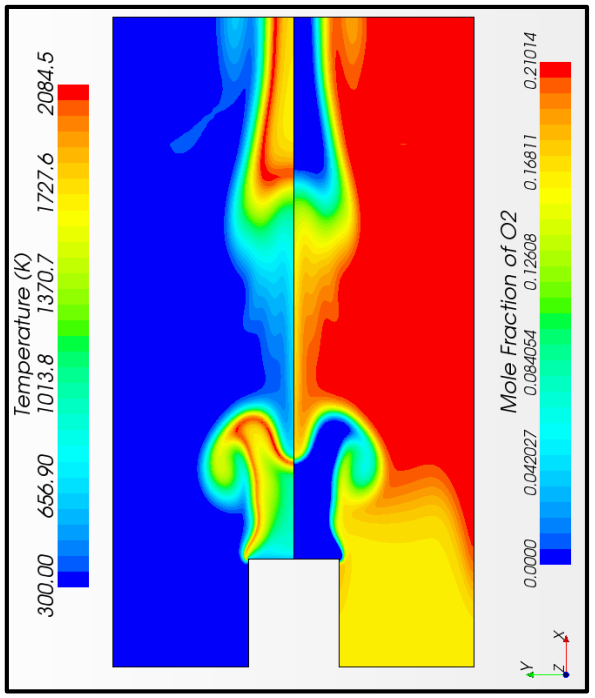
Cup-Burner Modeling
(Determine Flame Extinguishing Concentrations)



Ref. NRL Paper
(GMRES, 35 species, 217 reactions)

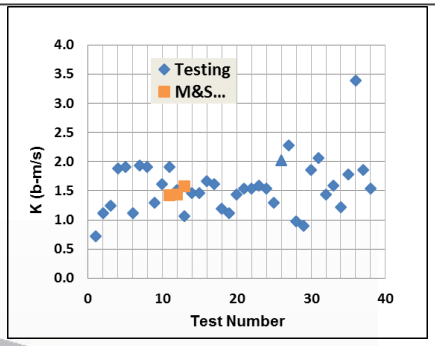


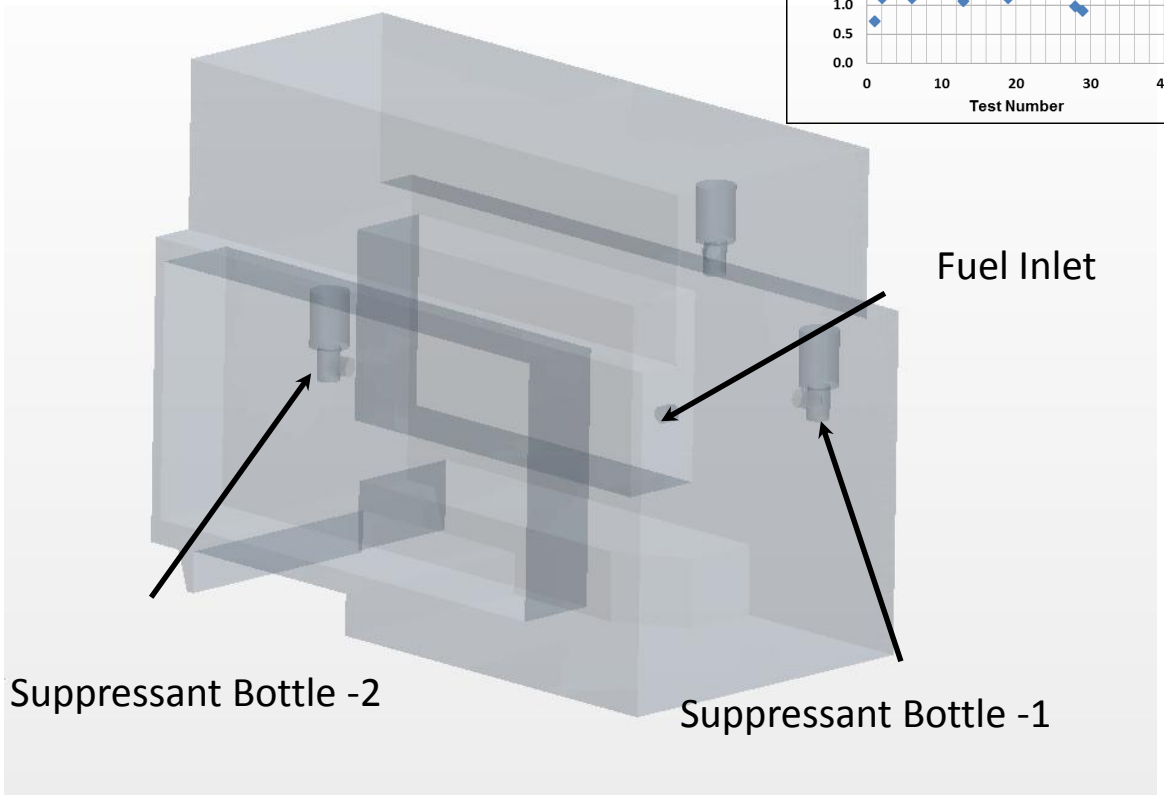
Uninhibited
(Two-step Global Reactions)



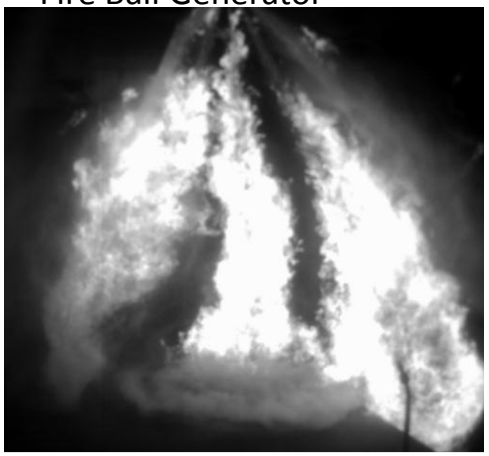
Inhibited With Nitrogen
(Two-step Global Reactions)

EXPLORATORY TEST BOX

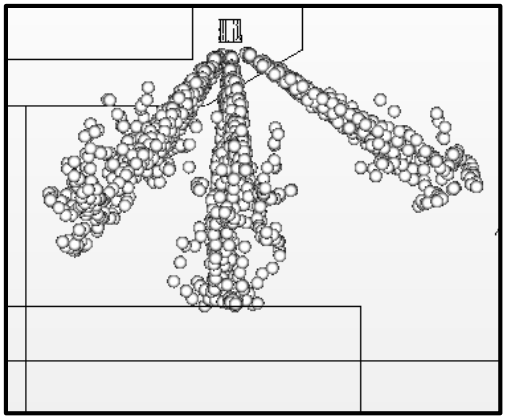




Fire Ball Generator

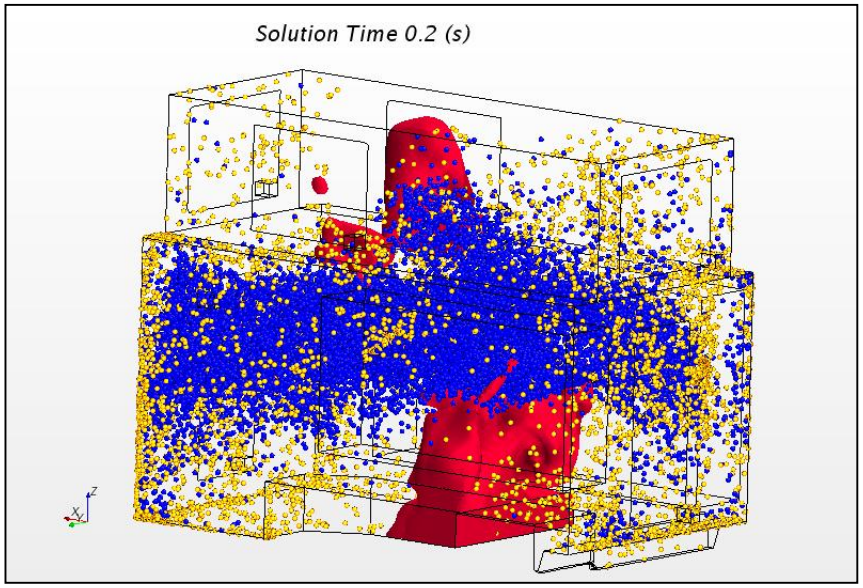


Fireball is based on a medium shaped charge penetration into fuel cell

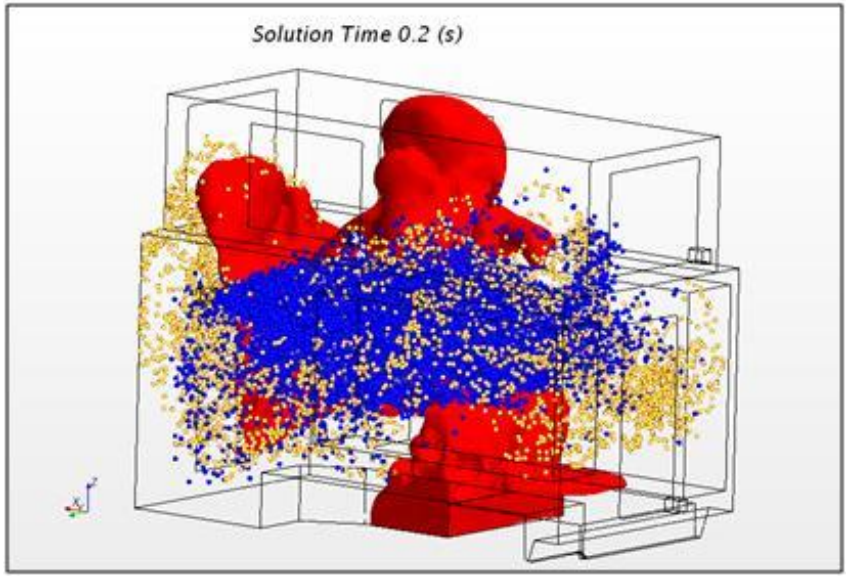


Reference: ***Fire Extinguishing Agents for Protection of Occupied Spaces in Military Ground Vehicles***

EXPLORATORY TEST BOX SIMULATIONS



Test Box (Successful Suppression)
Fire Ball (Red), SBC (Gold), HFC227ea (Blue)

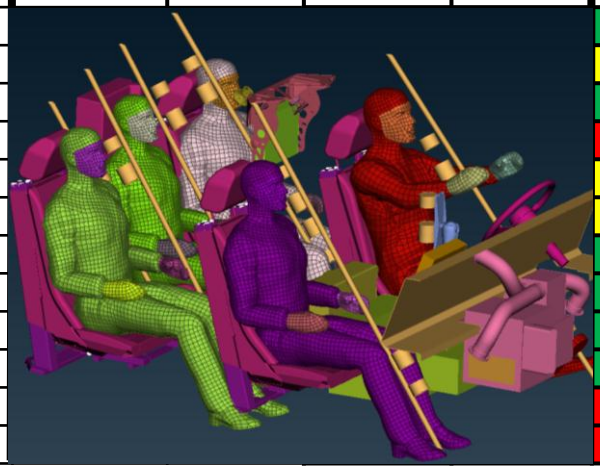


Test Box (Failed Suppression)
Fire Ball (Red), SBC (Gold), HFC227ea (Blue)

Criteria	Above Design Conc.		Below Design Conc.	
	Test	Simulation	Test	Simulation
Overall	Pass	Pass	Fail	Fail
Extinguish Flames without reflash	YES	YES	YES	No
K Value	1.56	1.44	1.14	1.44
HF Acid (PPM)	<20	47	3975	NA
COF2 Acid (PPM)	<20	97	1550	NA
Oxygen Levels	17.4%	18.0%	16.5%	NA

Comparison of FM200 Concentration (Test & Simulation)

Peak concentration levels measured within the 1st 200 and 340 ms

					11. Two-Nozzle @ 45° HVAC off (test)		11. Two-Nozzle @ 45° HVAC off (simulation)	
Position					200	340	200	340
Driver	Nose							
	Knee							
Commander	Nose							
	Knee							
Right Rear	Nose							
	Knee							
Gunner	Nose							
	Knee							
Left Rear	Nose							
	Knee							
FBG	Front							
	Rear							

270 ms Criteria

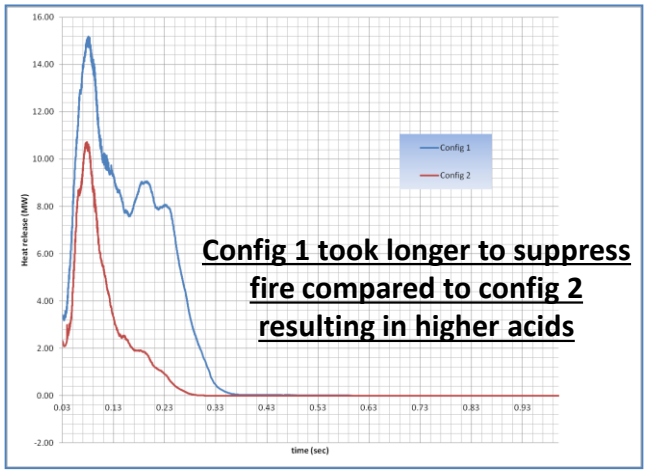
Peak > 8.7% : Good

6.7% < Peak < 8.7% : Acceptable

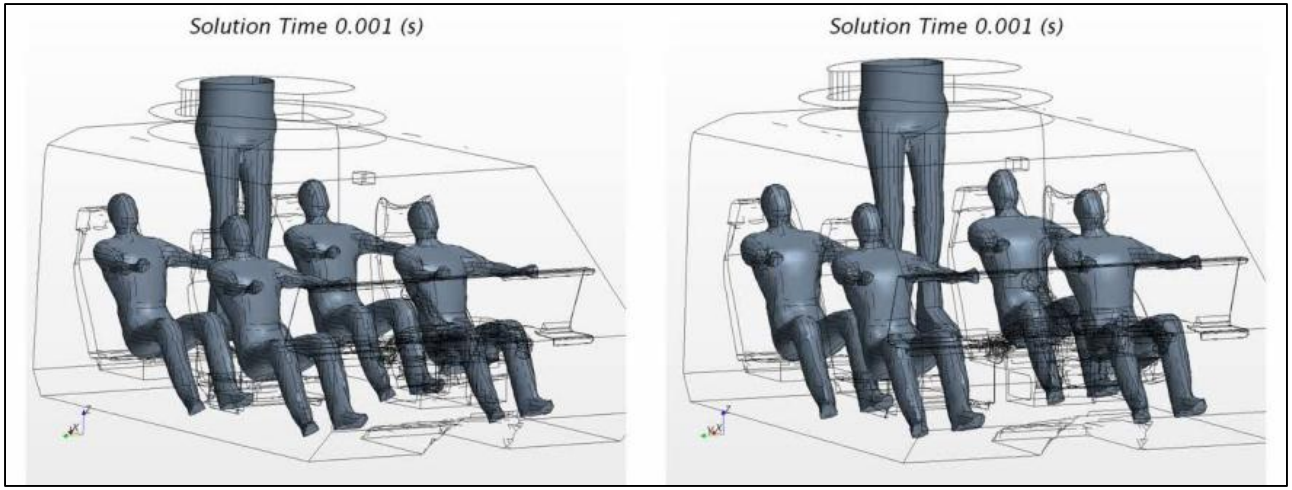
6.7% > Peak : Inadequate

Crew Compartment Nozzle Configuration Comparison

Configuration I



Configuration II



Nozzle Configuration Comparison
With HVAC Off

Comparison of Simulation with Test Data

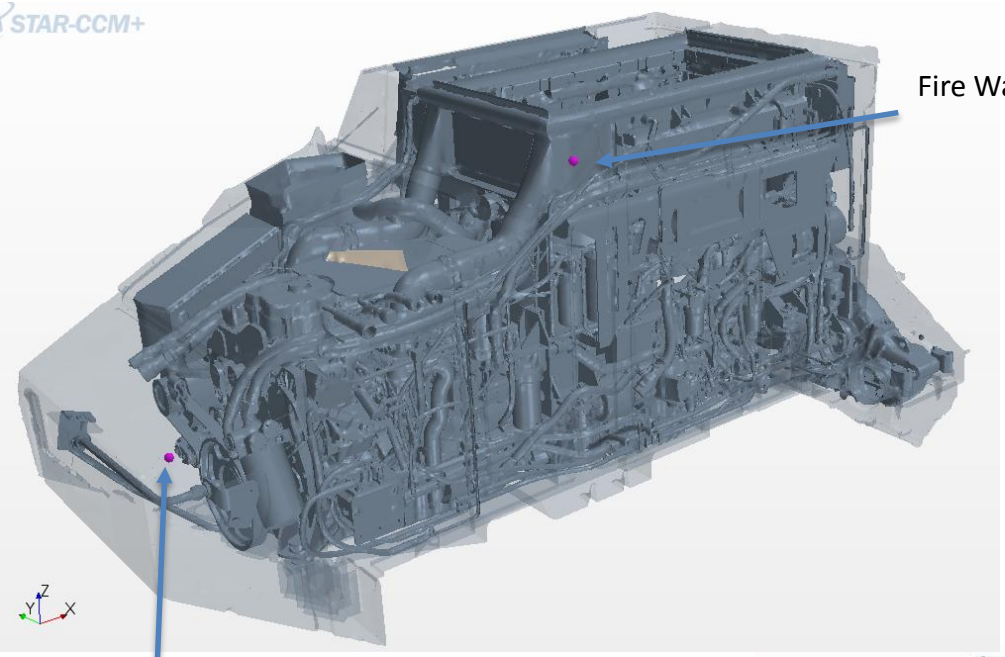
Criteria	Configuration I 		Configuration II 	
	Test	Simulation	Test	Simulation
Overall	Fail	Fail	Pass	Pass
Extinguish Flames without reflash	YES	YES	YES	YES
Overall Pressure (psi)	0.59	0.48	0.35	0.31
Agent Concentration	Below LOAEL	Below LOAEL	Below LOAEL	Below LOAEL
HF Acid (PPM)	708	656	<20	96
COF2 Acid (PPM)	161	518	<10	169
Oxygen Levels	15.9%	15.9%	17.1%	17.2%

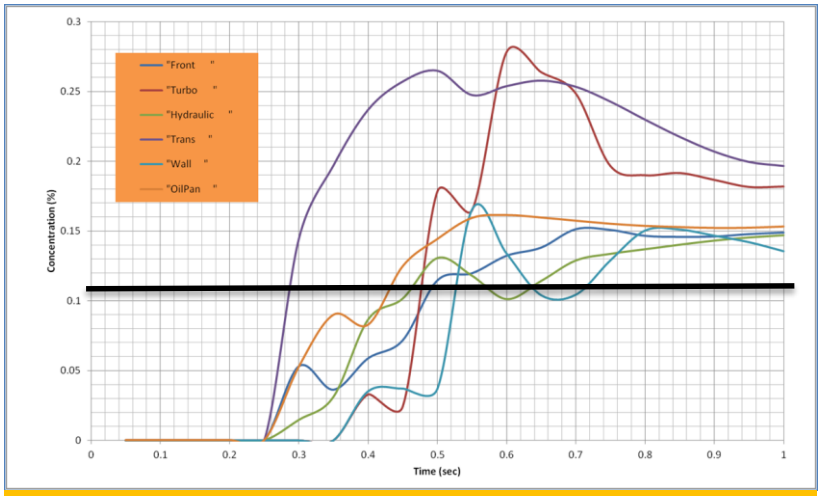
Typical measurements include high speed video, blast overpressures, temperatures and the chemistry of the atmosphere, in particular the combustion byproducts using Fourier Transform Infrared Spectrometer (FTIR)

Simulations done To-date for Crew Compartment

- With & without active air flow
- Fire Ball Generator (FBG) Location change
- Change nozzle parameters
  - number
  - location
  - discharge pattern
- Amount of agent & agent type
- Different clutter characteristics
- Hatch open vs closed scenario
  - RWS vs OGPK

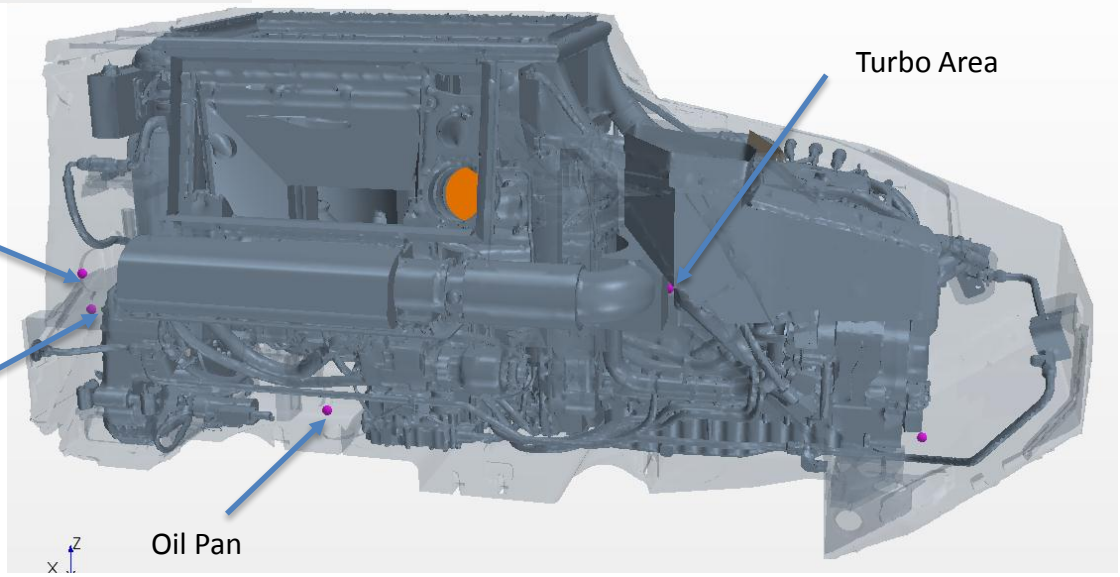
Engine Compartment Concentration Simulation



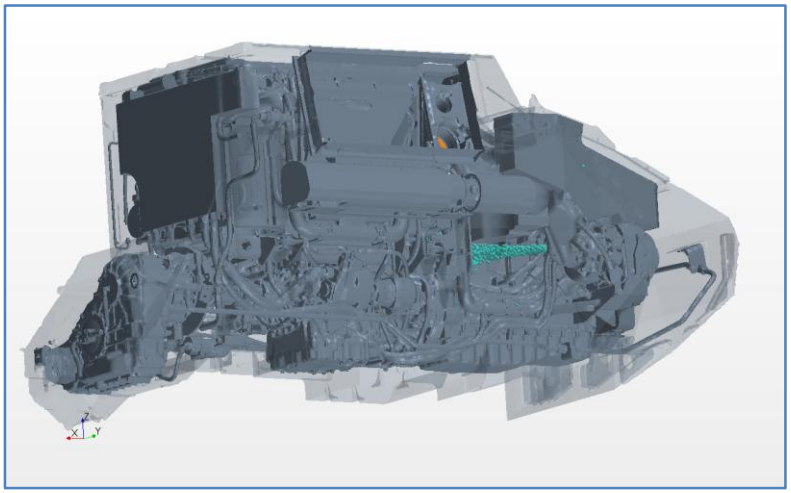


HFC125 concentration stays above design concentration after 1 sec duration with fan on.

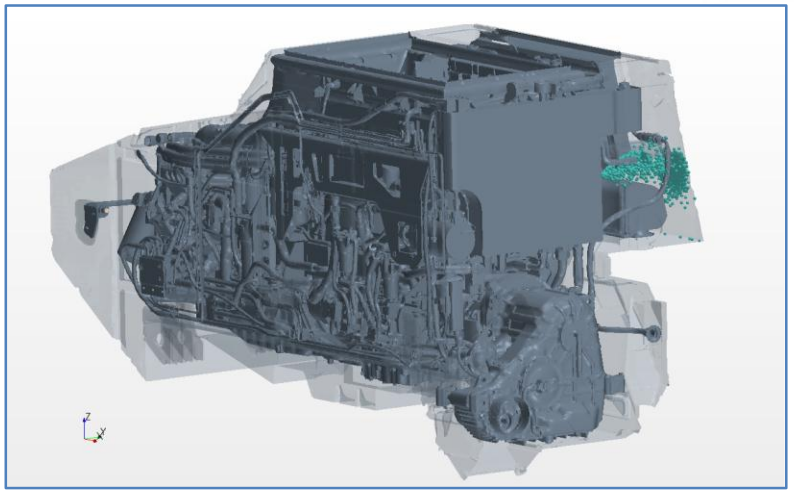
Engine Bay fan is set at design point



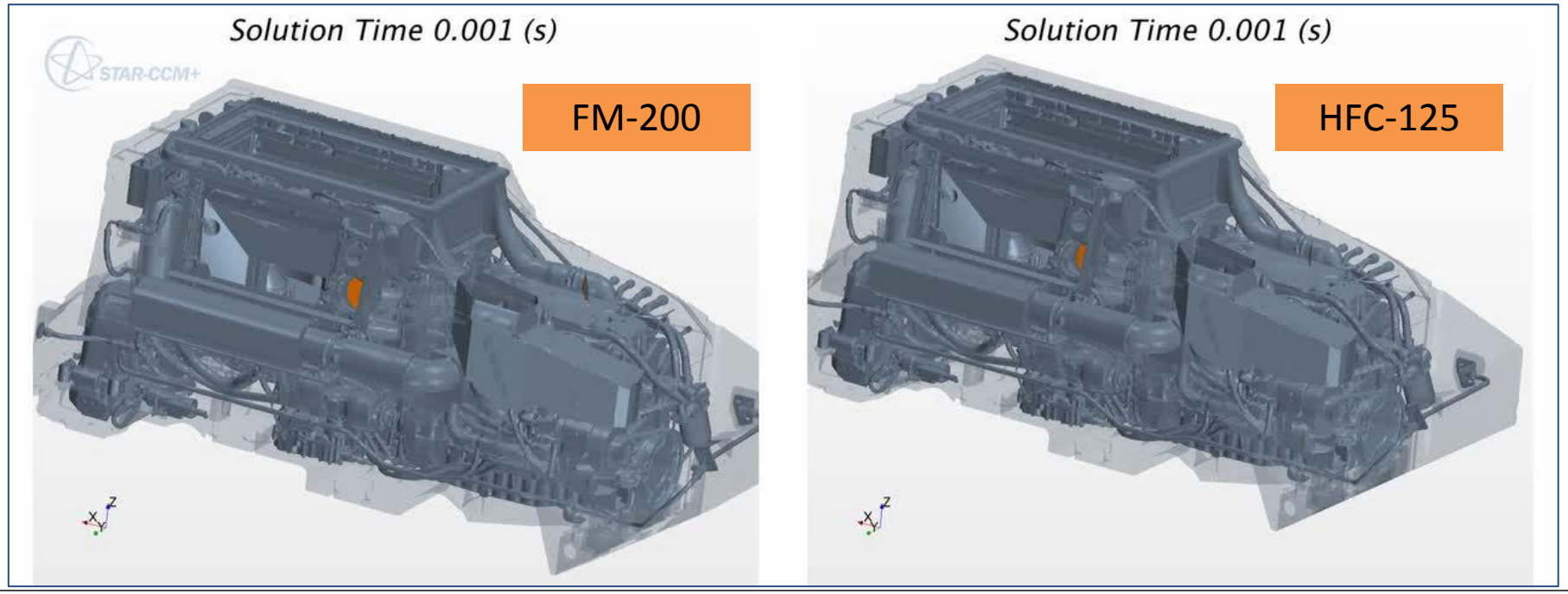
Engine Compartment Suppression



Hydraulic Fluid Spray onto Turbo



Hydraulic Reservoir Leak



Summary & Future Work

- Simulation Results Comparison with testing
  - Results are qualitative and to a extent, quantitative
  - Coarse grid implications (adjustment of activation energy, soot)
  - Suppressant Nozzle specification (cone angle)
  - Halon and Water+Potassium acetate validation is limited to-date

- Improve turn-around time
  - Status: 1-2 weeks for geometry preparation, 1 week for computation with DSRC HPC

- Atomization Specification (SWRI & ARL)
  - Scaling with Threat size
  - Phenomenological model

- Discharge of the suppressant (HAI effort)
  - Discharge Lag time, flow split etc.

- Nozzle Characterization effort (ADAPCO)
  - Droplet distribution
  - Velocity distribution
  - Cone Angle